EFFECT OF OPENING WITH VARIOUS SIZE AND LOCATION ON RC DEEP BEAM

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ABSTRACT

This study is about analysis of the behaviour of the reinforced concrete deep beam with different sizes of opening and different location of the opening by using ANSYS. The opening on RC deep beam is made for the mechanical and electrical purposes. Before the opening is made, it is important to know the optimum size and its location in order to prevent structural failure. The main objective of this study is to determine the effect of the opening size and its location on the reinforced concrete deep beam in terms of crack pattern and deflection. The study is conducted by using ANSYS 12.0. In this study, there are 7 models. There is one solid beam (DBS), three beams with different size of opening namely DBO1, DBO2 and DBO3, and three beams with opening but different location were designated as DBL1, DBL2 and DBL3. The three point test was used for the analysis. The loading used for the analysis is axial load. The deflection and the crack pattern obtained from the ANSYS were used for discussion. Based on the result, the deflection of the RC deep beam was increase in 31.2% as the opening size increase in 60%. For the different location of opening, as the location of opening move from 350mm to centre of the RC deep beam, the deflection of the RC deep beam was increased in 31.8%. In conclusion, the most appropriate location of the opening on RC deep beam is the place where far away from the loading.

ABSTRAK

Kajian ini adalah mengenai analisis kelakuan rasuk konkrit bertetulang dalam dengan saiz pembukaan yang berbeza dan lokasi pembukaan yang berbeza dengan menggunakan ANSYS. Pembukaan di rasuk konkrit bertetulang dalam dibuat bagi tujuan mekanikal dan elektrik. Sebelum pembukaan itu dibuat, ia adalah penting untuk mengetahui saiz optimum dan lokasinya bagi mengelakkan kegagalan struktur. Objektif utama kajian ini adalah untuk menentukan kesan saiz pembukaan dan lokasinya di rasuk konkrit bertetulang dalam dari segi corak keretakan dan lenturan. Kajian ini dijalankan dengan menggunakan ANSYS 12.0. Dalam kajian ini, terdapat 7 model, satu rasuk pepejal (DBS), tiga rasuk dengan saiz yang berbeza pembukaan iaitu DBO1, DBO2 dan DBO3, dan tiga rasuk dengan pembukaan tetapi lokasi yang berbeza telah dinamakan sebagai DBL1, DBL2 dan DBL3. Ujian lenturan tiga titik telah digunakan untuk analisis. Beban yang digunakan untuk analisis adalah beban paksi. Lenturan dan corak retak diperolehi dari ANSYS digunakan untuk perbincangan. Berdasarkan keputusan, lenturan rasuk konkrit bertetulang dalam meningkat sebanyak 31.2% apabila saiz pembukaan meningkat sebayank 60%. Untuk lokasi yang berbeza, pembukaan di lokasi dari 350mm ke pusat rasuk konkrit bertetulang dalam, lenturan rasuk konkrit bertetulang dalam telah meningkat sebanyak 31.8%. Kesimpulannya, lokasi yang paling sesuai untuk pembukaan pada rasuk konkrit bertetulang dalam adalah pada lokasi yang jauh dari pembebanan.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

The construction of tall building is different from the construction of a normal building. In the construction of the tall building, the beams at the lower part will carry larger loads when compare with the beams in a normal building. The deep beam was created to solve these problems.

A deep beam is a beam which has a deeper depth compared with a normal beam. In the ACI 318, it stated that a beam with the clear span equal to or less than 4 times the overall member depth, which is the depth of a deep beam, is comparable with its span length. To design a reinforced concrete deep beam, most of the engineers followed the strut and tie model (STM). The principle of the strut and tie stated that a truss is design as all stress are compacted into compression members and tension members connected by nodes. The members subjected to compression are strut; members subjected to tension are tie, while the intersection between strut and tie is node.

The deep beam has a larger depth because it is a load transferring structural component which is usually used to transferring a great amount of loads from above to supports at below. Deep beam usually used in the construction of high-rise buildings. In a high-rise building, the deep beam is used as a transfer girder. When a lower column was removed from the lower floor, the deep beam has to transfer the load from the upper column to the other lower columns. The application of deep beam can provide more space for the lower floor. The deep beam also used in concrete gravity foundation and bridge construction.

In a building, there are mechanical, electrical, and passage ways access that need to be consider during construction process. The larger size of deep beam will cause obstruction to these utilities. In some cases, these utilities have to penetrate the deep beams. The solution to solve this problem is providing opening at the beam. These openings are required for the passage utilities lines and ventilation ducts.

1.2 PROBLEM STATEMENT

The openings on a structural element were made for mechanical and electrical purposes. From the view point of a structural engineer, there are some difficulties to make decision when the openings are required to be made on the reinforced concrete deep beams. This is because there is no code of design for structural with openings. The effect of making opening on the RC deep beam is unpredictable. The opening may reduce the strength of the RC deep beam will lead to structural failure. Therefore, the analysis of the structural elements with web openings should be conducted before the web opening made for the safety of the RC deep beam.

For the mechanical and electrical purposes, there are many essential ducts will be installing in a building and sometimes there need to penetrate the concrete deep beams. The ducts to be used in mechanical and electrical purposes are various in sizes. Because of the size of ducts are various, the size of opening on the beam will be various. Besides that, the system routing for the essential ducts are very complex in the large structural. This will caused various location of the opening on beam. The optimum size and location of the opening have to be determined. So that the study on the size and location of the opening on deep beam may be useful and need to be take note.

1.3 OBJECTIVE OF STUDY

The main objectives of this study are:

(i) To study the effect of the size of opening on deep beam based on crack pattern and mid span deflection.

(ii) To study the effect of the location of the opening on deep beam based on crack pattern and mid span deflection.

1.4 SCOPE OF STUDY

In this study, the model of solid RC deep beam was adopted and modified from previous study by Preetpal & Nasir (2014). The dimension of the RC deep beam models was 2300mm length, 150mm width, and 800mm depth. There are total of 7 models were analysed in this study. A solid deep beam model was used as controlling model, which is a reinforced concrete deep beam without any opening. There are 6 models with opening were analysed. There were different in the size of opening and the location of the opening. According to Ashraf (2014),the overall reduction in the beam's capacity should not exceeding 10% of the capacity the beam without web opening, the diameter of the opening should not exceed 20% of the beam overall depth (0.2d). The size of the opening was set with diameter of 100mm, 130mm, and 160mm. The models are shown in Figure 1.1 and Figure 1.2 below. The size and location of the web opening on the deep beam is shown in Table 1.1.

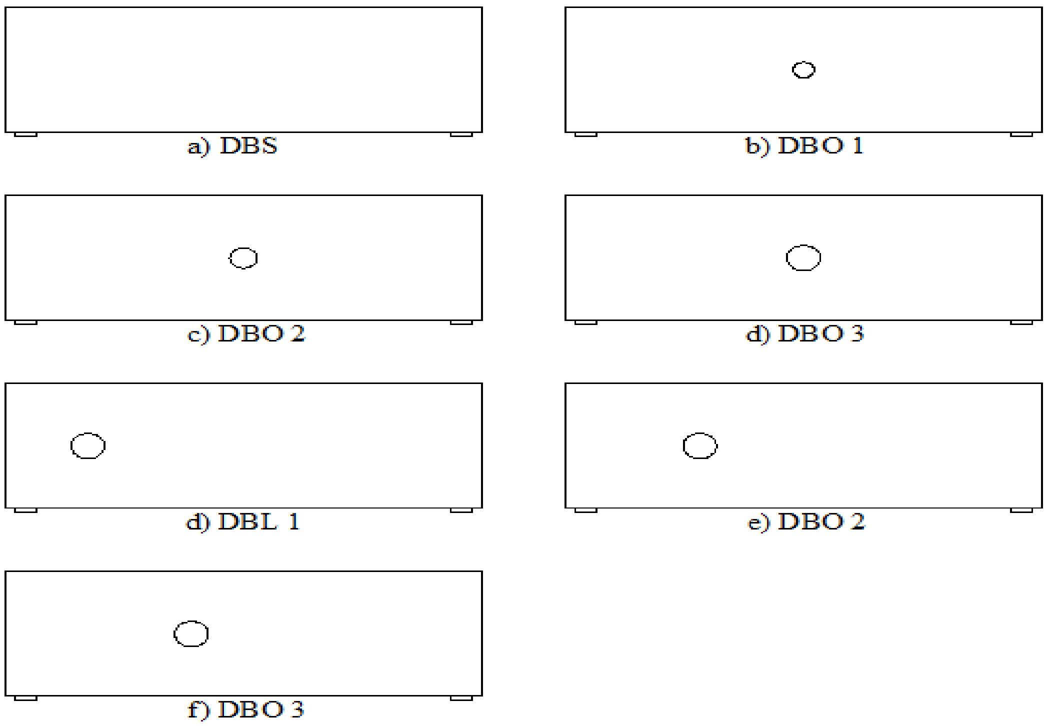


Figure 1.1: Models of the analysis

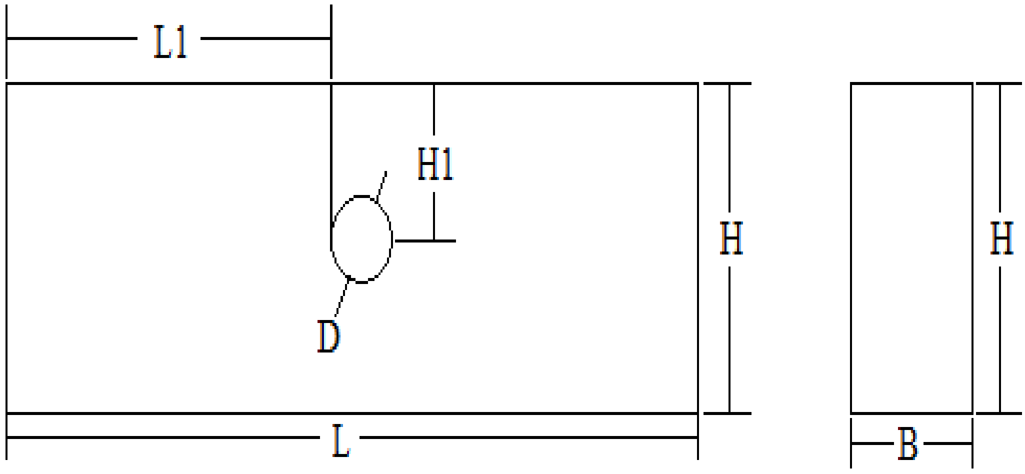
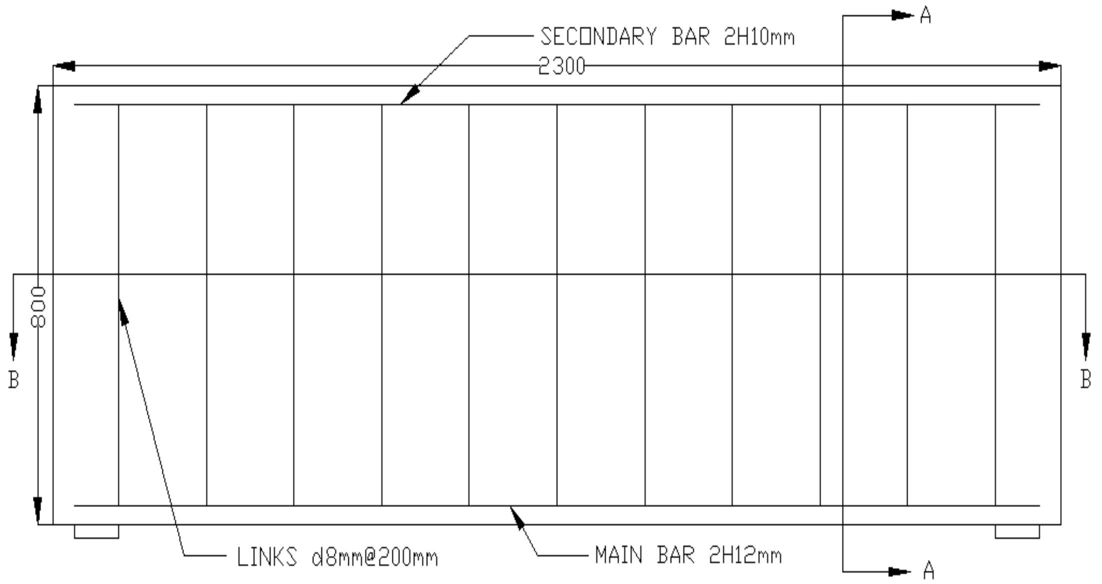


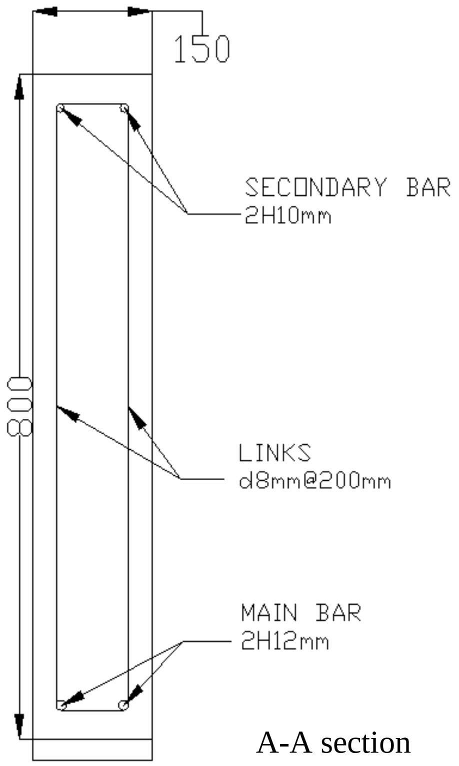
Figure 1.2: Location of the opening on the deep beam

Table 1.1: Dimension of the models and the detail of opening

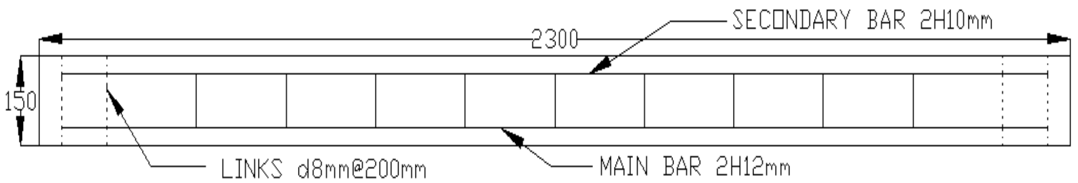
BEAM	SIZE OF BEAM (B*H*L)	SIZE OF OPENING (D)	LOCATION OF OPENING	
			L1	H1
DBS	150x800x2300mm	-	-	-
DBO1	150x800x2300mm	100mm	1100mm	400mm
DBO2	150x800x2300mm	130mm	1085mm	400mm
DBO3	150x800x2300mm	160mm	1070mm	400mm
DBL1	150x800x2300mm	160mm	320mm	400mm
DBL2	150x800x2300mm	160mm	570mm	400mm
DBL3	150x800x2300mm	160mm	820mm	400mm

The tension longitudinal reinforcement used was 2H12mm and for the compressive longitudinal reinforcement was 2H10mm. The deep beam was reinforced vertically with shear reinforcements consisting of d8@200mm. The reinforcement bars configuration of the RC deep beam was shown in Figure 1.3. The section view of the reinforcement bars configuration also showed in the Figure 1.3.





A-A section



B-B section

Figure 1.3: Reinforcement bars configuration and its section views

When the opening was located intersect with the shear reinforcement bars, the shear reinforcement bars was removed as shown in Figure 1.4. The red line showed the shear reinforcement bar that was intersecting with the opening.

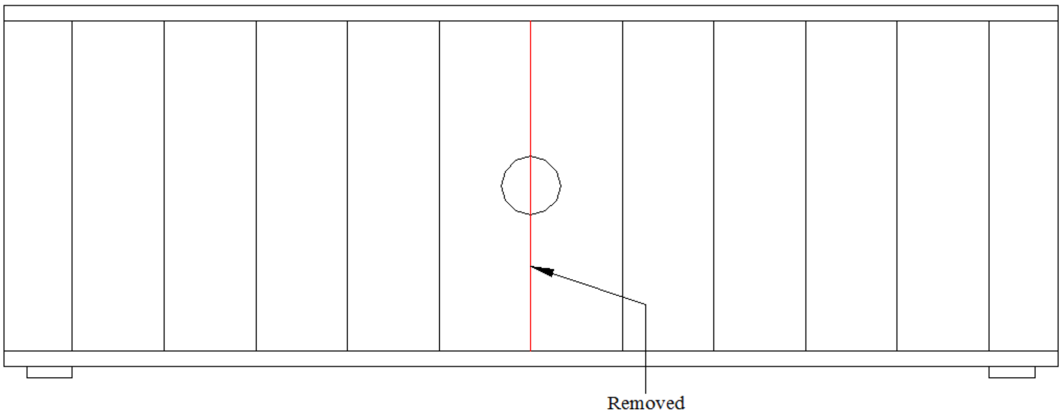


Figure 1.4: Reinforcement bar configuration when there is opening

This study was conducted by analyse the models by using the software called Civil FEM with ANSYS. To do the study on the flexure behaviour (deflection and the stress distribution) of the RC deep beam with web opening, the three-points bending test was conducted. The loading was put at the mid span of the deep beam. There are steel plates were placed at the supports. For the boundary condition for the deep beam model, the displacement was in the direction which is perpendicular to the plane is zero. For this study, one end was roller, while another end was fixed.

The input data for material properties of the concrete and the reinforcement bars in ANSYS were shown in the Table 1.2 and Table 1.3.

Table 1.2: Material properties of concrete in ANSYS

Material properties of concrete	
Elastic modulus, E_c	20,000 MPa
Poisson's ratio, v	0.2
Open shear transfer coefficient	0.5
Closed shear transfer coefficient	1
Uniaxial cracking stress	2.5MPa
Uniaxial crushing stress	25MPa

Table 1.3: Material properties of reinforcement bars in ANSYS

Material properties of reinforcement bars	
Elastic modulus, E_s	200,000 MPa
Yield stress, f_y	450 MPa
Poisson's ratio, v	0.3

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

A reinforced concrete deep beam is a common structural element used in high-rise building, off-shore structural and foundation structural. It is a load transferring structural component which is usually used to transferring a great amount of loads to supports.According to ACI 318, it stated that a beam with the clear span equal to or less than 4 times the overall member depth or a beam with concentrated loads within a distance equal to or less than two times the beam depth from the face of support is defined as deep beam.

2.2 ADVANTAGES OF DEEP BEAM

In construction of high rise building, a deep beam is used as transfer girder. By using deep beam, the number of columns below the deep beam can be reduced. This is because a deep beam has a higher ultimate load capacity compared to normal beam. It is a load transferring structural component which is usually used to transferring a great amount of loads to supports.

By using RC deep beam as the transfer girder, it can provide more space at lower floor. This is because of the high strength of the RC deep beam, it can carry higher loads from above, and thus the column below it can be removed. There will be more space below when the columns were removed.

2.3 APPLICATIONS OF DEEP BEAM

Reinforcement deep beams have many applications in buildings, bridges, offshore structures and foundations. Because of its high ultimate load capacity, it is commonly used in huge structural. In recent years, the deep beam is widely used in construction. Deep beams are usually used as transfer girder in high-rise building, pile caps, foundation wall as well as shear wall.

2.4 STRUT AND TIE METHOD

Strut and Tie method (STM) is a method used to design the reinforced concrete deep beam. By using this method the complex stress at the discontinuity region was simplified by theory in truss. Each uniaxial stress path is a member in STM. With this method, tension members are called tie, while compression members are called struts. The intersection points between struts and ties are called nodes. Ties are the location where reinforcement bars should be placed. The angle between the diagonal compression strut and the tension tie is limited to not less than 25 degree. Figure 2.1 showed the members in deep beam with STM.

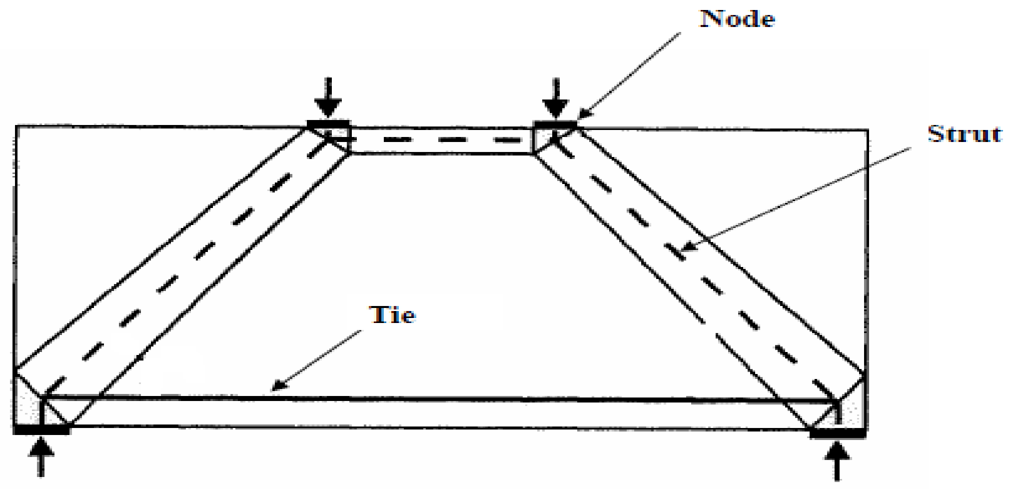


Figure 2.1: Members in Deep Beam with STM

Source: Barney 2007

Struts are compression members in a deep beam. According to study by J.Schlaich and K. Schlaich (1991), there are three types of struts which are bottle-shaped struts, prismatic struts, and compression fan struts. The different type of struts is caused by the force path in the deep beam. An illustration of the different geometric shapes of struts is shown in Figure 2.2.

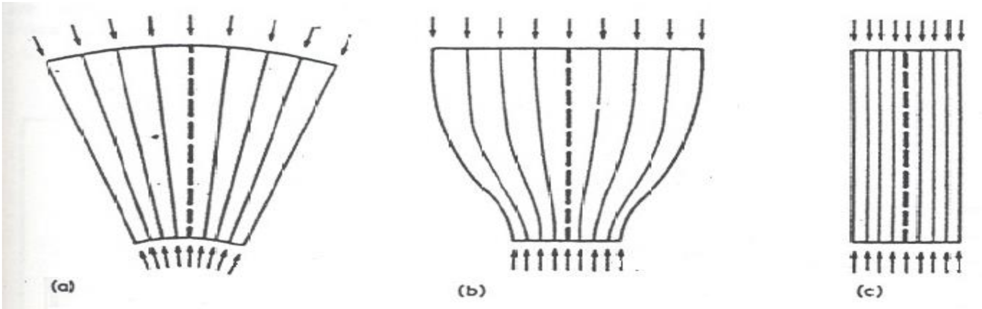


Figure 2.2: Geometric shapes of struts, (a) fan compression, (b) bottle shaped, (c) prismatic

Source: J.Schlaich and K. Schlaich 1991

"Structural behavior of RC deep beam with headed longitudinal reinforcements" by Soo (2004), this study showed that the STM Model was conservative and showed lowest standard deviation among several design methods in predicting shear strength of deep beam. Thus, it can conclude that the STM is a most desirable method for design of RC deep beam.

2.5 CODE PROVISION FOR STM

There are many reinforced concrete design codes including CSA A23.3, ACI 318 and Eurocode 2 accepted the STM after evaluating the model against experimental investigations.

2.5.1 CSA A23.3

According to CSA (2005), the STM is a suitable method to design deep flexural member. CSA A23.3-04 states that the deep flexural member is the flexural member with a clear span to overall depth ratio less than 2. The non-linear distribution of strains should be considered when design a deep flexural member.

The web reinforcement for deep flexural members should be not less than 0.2% of the gross concrete area in the horizontal and the vertical direction. There should be an orthogonal grid of reinforcement close to each face of the deep beam. This reinforcement should have spacing not more than 300mm in each direction.

2.5.2 ACI 318

The ACI 318 (2008) defined the deep beam as: (a) clear span equal to or less than four times the overall member depth; or (b) regions with concentrated loads within twice the member depth from the face of the support". According to ACI 318, the strength of the strut is depending on the geometry of the strut, and the presence of reinforcement bars and how they were distributed across the strut.

2.6 ANSYS MODELING AND ANALYSIS ON DEEP BEAM

ANSYS is software that can be used to solve variety problems. **ANSYS** is the most advanced, comprehensive and reputable finite element analysis and design software package available for civil engineering projects. The solid RC deep beam and the RC deep beam with opening are analyze by using the finite element model in ANSYS.

2.6.1 Concrete in ANSYS

"SOLID 65"in ANSYS is used for 3D modeling of the concrete with or without the reinforcement bars. It is used to model the concrete element. 8 nodes will be created, the nodes will be joining up by line and the volume will be defined as concrete. Each node is having 3 degree of freedom. The concrete model is a solid concrete model without any rebar. "SOLID 65" is an element which is capable of cracking in tension and crushing in compression. Figure 2.3 showed the element with eight nodes.

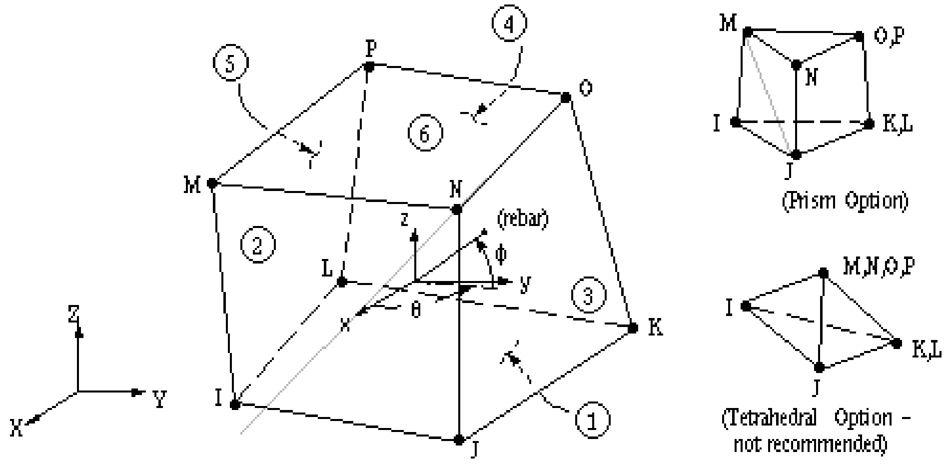


Figure 2.3: Geometry of SOLID 65

2.6.2 Steel Plate in ANSYS

"SOLID 185" in ANSYS was used to modeling the solid structures. In this study, it was used to define the steel plate of the model. In ANSYS modelling, the steel plates are used for the supports and loading. The purpose of steel plate is to distribute the stress evenly. The "SOLID 185" is defined as 8 nodes volume with 3 degree of freedom for each node. An illusion of element SOLID 185 is shown in Figure 2.4.

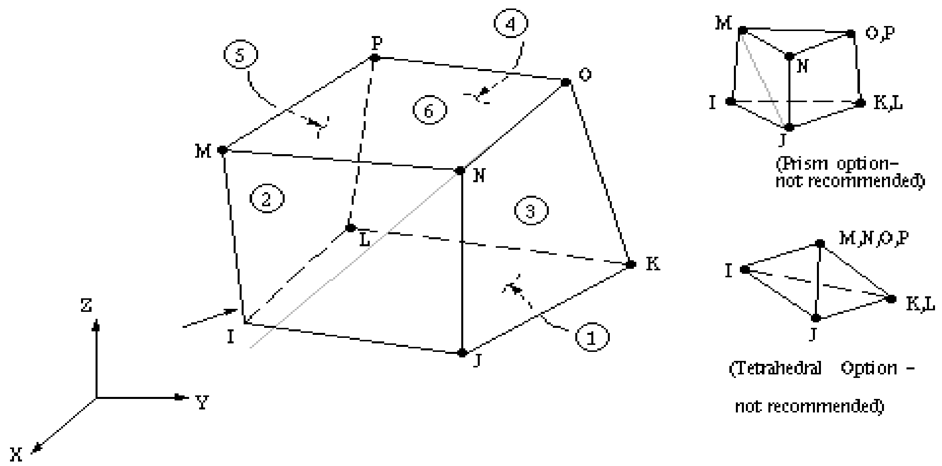


Figure 2.4: Geometry of SOLID 185

2.6.3 Reinforcement Bars in ANSYS

"LINK 180" is a spar which may be used in a variety of engineering applications. The reinforcement bar is defined by "LINK 180" in ANSYS CIVILFEM. The 3-D spar element is a uniaxial tension-compression element with three degrees of freedom at each node. The rebar and the concrete will automatic bonded perfectly when the node of rebar aligned with the node of concrete. Figure 2.5 showed the element, LINK 180, with two nodes.

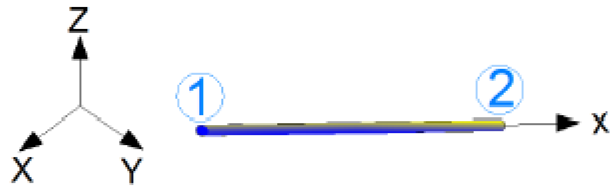


Figure 2.5: Geometry of LINK 180

2.7 EFFECT OF OPENING TO STRUCTURAL ELEMENT

Preetpal and Nasir (2014), an experiment was conducted to test the effects of static loading on RC beam with openings in the critical tensile zone. The concrete structural will reduce in strength when there is opening on it. This is because the load capacity reduces with the opening.

In the study made by Lee et al. (2008), there are total 5 deep beams with the circular web opening have been tested to evaluate the shear strength with the various location of web opening. They found that the deep beam with opening will has a steeper slope for the load-deflection curve when compared with the solid deep beam.

In the study conducted by Asraf et al (2014), there are three parts. One is three points test, and another one is four points test. The third is the test for continuous deep beam. The parameter of this study is the loading scheme, the location of web openings and the reinforcement distribution. There is about 35% reduction in load capacity of the deep beam when the web opening located crossing the compression struts between the load and the support.

From the study done by Heather (2010), a doubly reinforced concrete beam with a circular opening at mid-span was modelled and analysis by using ANSYS. The main objective is to determine the stress distribution around the circular opening. The stress concentrates at the top and bottom of the circular opening before the deep beam cracks. The flexural cracks form at the bottom of the opening because of the stress concentration.

2.8 EEFECT OF THE SHAPE OF THE OPENING

A study made by Soroush and Reza (2011), the research is study on the effect of circular opening size on the behaviour of beam. The beam models were created with circular opening and equivalent square opening. From the result, they found that the beam with circular opening will has higher strength in ultimate load capacity when compared with the beam with equivalent square opening.

According to research done by Haider (2013), the effect of the opening shape on the structural behaviour of the reinforced concrete deep beam with openings has been investigated. The result of the research showed that the best shape to be made for the web opening is the narrow rectangular. It can save up 40% of structural strength of the deep beam. But in real case, the rectangular shape is not suitable.

2.9 EFFECT OF THE LOCATION OF THE OPENING

The study “effect of opening sizes and locations on the shear strength behaviour of RC deep beams without web reinforcement” has been done by HawrazKarim el at (2013). The results showed that the opening at shear zone will has a larger effect, while the opening at the mid-span will has small effect to the shear strength.

“Design of concrete deep beams with openings and carbon fibre laminate repair”, by Son (2002), in this research, there are 12 concrete deep beams with and without openings were designed and then tested to validate the effectiveness of the design method. In the results obtained, the results showed that when the opening located at the place that did not interrupt the natural load path of the beam, the beam will behave like a solid deep beam.

According to the study done by Ashraf at el (2014), “prediction of the behaviour of reinforced concrete deep beams with web openings using the finite element method”, the results of this study showed that when the opening was placed at the location where crossing the expected compression struts developed between the load and the supports, the beam’s capacity was reduced more when compare the opening located at the place where it does not interfere with the load path.

2.10 FAILURE MODE OF BEAM

The concrete structures may be subjected to various loading during its service life. The cracks caused by loadings will affect the structural behaviour of the structural element.

2.10.1 Beam-Type Failure

In this type of failure mode, the failure plane is 45^{o}inclined. The failure plane is being cross the centre of the opening. It may be seen that the stirrups available to resist shear across the failure plane are those by the sides of the opening. An illusion of the beam-type failure is shown in Figure 2.6.

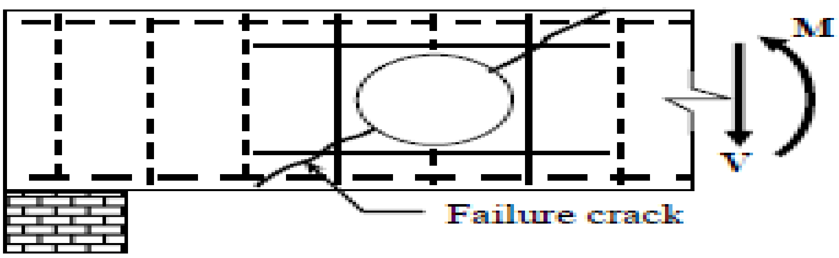


Figure 2.6: Beam-type failure

Source: Mansur 1998